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Engineer Research and Development Center

Energy-Efficient Buildings Through Design Automation

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Foreword

This study was conducted for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers (HQUSACE) under Project 40162784AT45, "Energy Systems for Design and Construction Processes"; Work Unit XA0, "Facility Design Optimization for Energy." The technical monitor was Justin Taylor, CEMP-FE.

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1 Introduction

Background

Since the mid-1970s, the Department of Defense (DOD) has pursued a strategy of increasing the energy efficiency of its buildings, both in new designs and in existing facilities. While designers have effectively produced more energy-efficient buildings, they are also under constant pressure to reduce facility delivery times, first cost, and maintenance requirements. At the same time, they must address design considerations such as aesthetics, indoor air quality, and occupant comfort—all factors that can be at odds with minimum energy consumption. For these reasons, energy efficiency is a chronic problem that depends on continued determined efforts to achieve DoD goals.

While popular sentiment may hold that the "energy crisis" is over, the emphasis from the Federal Government remains. Executive Orders (EOs) have repeatedly set energy reduction goals. In 1998-1999 alone, three EOs were issued that directly or indirectly relate to the problem of energy consumption in buildings. EO 13123, "Greening the Government through Energy Efficient Management," has the most obvious and direct correlation with energy-efficient building design. This EO also emphasizes "Sustainable Design" principles for all Federal building initiatives. EO 13101, "Greening the Government through Waste Prevention, Recycling, and Federal Acquisition," likewise challenges the building industry to consider minimizing impact to the environment during construction as well as in everyday operation. Draft EO "Developing and Promoting Biobased Products and BioEnergy" illustrates some of the continued emphasis.

The U.S. Army Corps of Engineers (USACE) has also issued guidance and implementation documents on Sustainable Design (e.g., ETL 1110-3-491). These documents can be accessed through the USACE website:

(http://www.hnd.usace.army.mil/techinfo/index.htm)

and recently updated design document dissemination:

(http://www.hnd.usace.army.mil/techinfo/misc/pubchg.pdf)

Modern information technology offers efficient ways to consolidate, organize, and share the content of laws, regulations, and the guidance and implementation documents that relate to building design. Some computer programs already exist (and others are under development) to help building designers incorporate energy-efficient design measures into new and existing buildings, and to coordinate energy-related considerations with other competing design factors. This study undertook a review of current practices and technologies that may help building designers better incorporate energy efficiency into all design phases.

Objective

The objective of this work was to review and summarize current technologies that can provide tools, techniques, and design practices to increase the energy efficiency of building designs—in new construction, and also in retrofit or remodeling projects.

Approach

1. Laws, EOs, regulations, and Corps guidance and implementation documents that govern or affect the building design process, especially as it relates to energy efficiency, were reviewed.
2. A literature search was also done for recent material related to the incorporation of energy efficiency into all stages of the building design process, and related to the coordination of energy-efficient technologies and design with other factors in the design process.
3. Software tools, techniques, and design practices that may help building designers effectively incorporate energy efficiency into building design were reviewed.
4. The results were consolidated, conclusions drawn, and recommendations made to guide the direction of future research and development in this area.

Mode of Technology Transfer

Primary mode of technology transfer will be through delivery as a MDS 2 add-on. It is also anticipated that the material developed for this study will be published as a technical paper at one or more professional society meetings (ASHRAE, AIA and ACME).

2 Traditional Building Design

In 1998, a group of designers performed an exercise to generate a list of "best available" energy design practices (Energy Targets 1998). During a simple "brainwriting" session, 132 potential ideas were generated that would help save energy during the facility operation. However, in the same session, 59 barriers were identified that would countermand many of the energy savings. The solution to saving energy in buildings cannot be accomplished by a single design discipline. Typical design practice (such as checking a building design for energy target compliance) has used the mechanical designer/engineer as the "energy engineer" even though energy considerations cross design disciplines much as cost considerations do.

In *Applying Collaborative Engineering to the Facility Delivery Process*, Brucker (1998) notes that:

> The Construction Document process consumes the greatest amount of time and resources, which leaves very little time for the designer to analyze designs, check alternatives, and negotiate conflicts with other design disciplines during the schematic design phase.

Designers do the best they can, but as noted above, the current reality of the building design process is that designers are overwhelmed with a plethora of changing criteria, technical letters and notes, design guides, charts, and manuals. The schematic design activity is consumed with addressing these changes, which leaves little time to devote to creating an optimal, energy-efficient building. Moreover, energy consumption is not the only consideration for an "optimal" design. Other factors in the "optimal" solution include: least life cycle cost, lowest first costs, least maintenance costs, and least environmental impact.

Design criteria (including, but not limited to the energy criteria discussed in the Introduction) are constantly changing. Some design shops rigorously scan for new criteria at the start of each project (Fort Worth District 1999). With the advent of the World Wide Web and (more recently) the Corps' *techinfo* site, this has become somewhat easier, although the search-and-review process is still far from automatic. "Appendix C: Internet Resources" includes a wide range of examples (web sites, newsgroups, email lists, and even design and analysis tools). Finding information is no longer the problem. The key challenge is to identify appropriate technologies and to make decisions with respect to guidance, criteria, and the design considerations listed above.

To this end, Osborne had a vision:

> My desire years ago (pre-WEB page era) was for a single DOD document with basic design criteria (all disciplines). That document would have a sub-document produced by each command that was an "errata" to the basic document. Each end user would produce an "errata" document to the first two. A review of all documents would be generated every three years with consensus on items that should be put into the basic DOD document and each errata corrected to reflect the changes. By the way, I also wanted a point of contact on each item of the two sub-documents. Many times, designers need guidance on what was intended, and when revisions are made the author should be consulted. Given today's technology, with links embedded in documents it would be easy to ask questions by e-mail.

This vision is referenced in subsequent sections.

3 Automating Criteria-Based Design

The following definitions are used throughout the discussion in this chapter:

- **Criteria** – an established set of design guidelines
- **Requirements** – a set of needs generated by the client and designers
- **Constraints** – a set of (often conflicting) limits placed on design solutions
- **Technical Solution** – a means (real or virtual) of meeting requirements.

Design is the act (or art) of selecting technical solutions that meet the requirements and represent the best compromise between constraints. Criteria provide the rules for applying technical solutions. Stated another way, requirements and constraints are the project-specific "yardsticks" used to down-select from the universe of criteria and technical solutions.

Designers are inundated with criteria and technical solutions from many sources, formats, and types of media (paper, CD-ROM, and the Internet). Osborne's vision was for someone to distill all these sources into a single work, which could be tailored to local conditions and individual preferences. This would embody the best practices of the Corps/District/Individual in a form that could be readily applied to satisfy the requirements and constraints of the project at hand.

Building Composer

Building Composer is a suite of tools whose functionality currently ranges from creation of architectural programs to facility layout. Each of these tools has access to the project's criteria, which is imported from libraries that can be tailored to meet the needs of a specific client, location, or individual.

Building Composer provides the technology to take Osborne's vision one-step further, by injecting criteria directly into the design process, rather than providing a static reference document. The central concept is both simple and extremely powerful: *to associate criteria with the building model.*

The building model used by Building Composer is based on the standard developed by the International Alliance for Interoperability (IAI). A particular criterion may apply to one or more levels in the product model (Heckel 2001):

- Project
  - Site
    - Function (space type)
      - Space
  - Building
    - Story
      - Function
        - Space

For example, General Illumination (lumens) applies to Building, Story, and Function (Office, Parking, etc.) although the value would be different for each case. On the other hand, it makes sense to specify the Energy Budget (J/m^2) for a Building, but not for a Site.

Criteria Composer

Criteria Composer is the tool used to create an architectural program. Although the Criteria Composer development team was unaware of Osborne's vision, the similarities are uncanny. Criteria is partitioned into Criteria Sets, which are typically displayed on discipline-specific tabs (Figure 1).

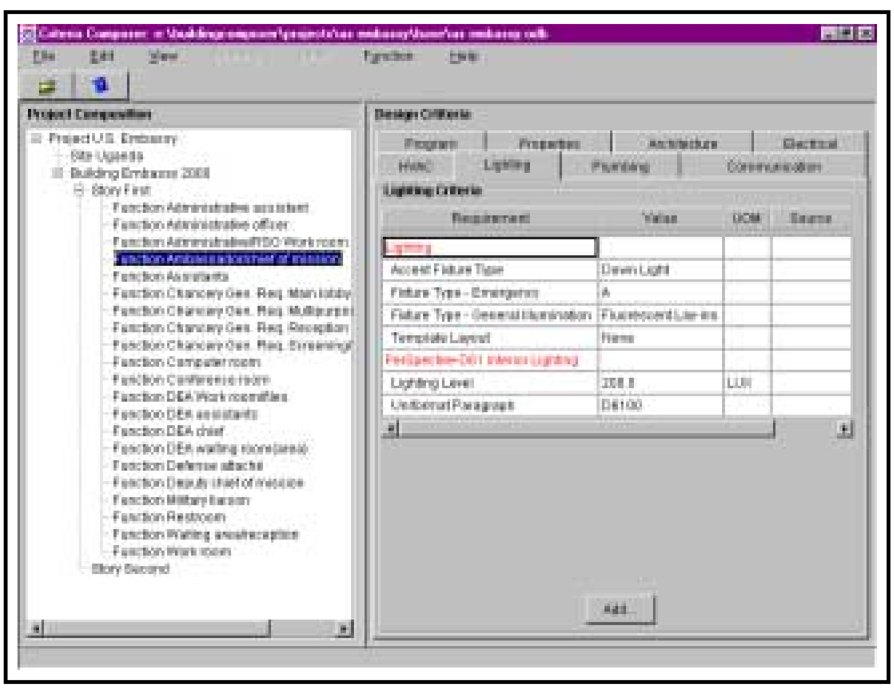

Figure 1. Criteria Composer discipline-specific design criteria.

4 Collaborative Building Design

Brucker (1988) observed that :

> With a Collaborative Engineering (CE) approach, it is estimated that the Corps' facility delivery time will be decreased by 50 percent and the resulting facilities will be more useful and efficient throughout their life cycle. With CE technology, it will be possible to produce 80 percent of the construction documents, save 3 to 9 percent of the construction costs, and reduce facility delivery time from 551 to 115-214 workdays. As a conservative estimate, well-designed buildings will use 25 to 35 percent less energy for heating and cooling during their life cycle.

The question to address here is how this can be realized to achieve our energy goals. The design process and the way in which energy aspects enter the building design, can be likened to the Maslow "Hierarchy of Needs" (1987). From a mechanical engineer's perspective, the basic need is to satisfy the heating and cooling requirements for the occupants. Figure 2 shows other levels.

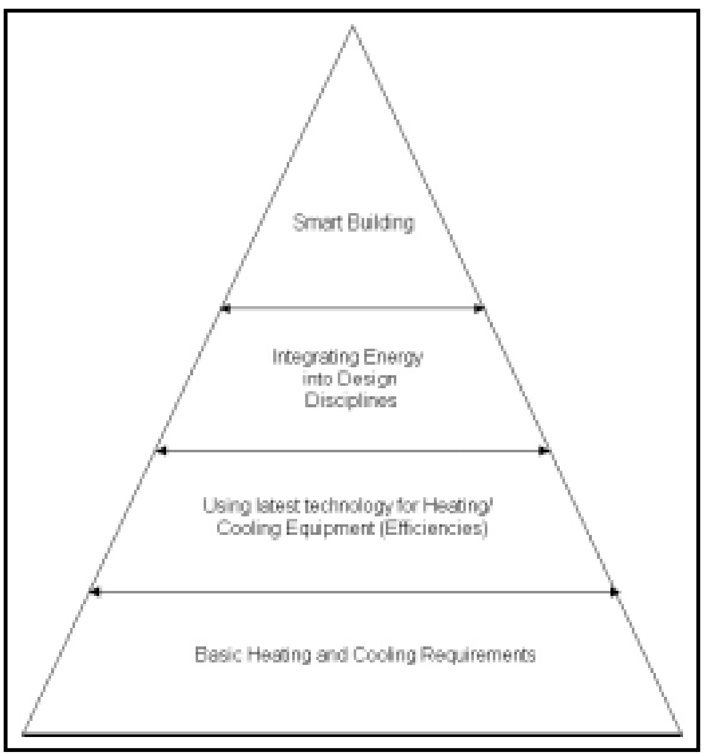

Figure 2. Energy "hierarchy of needs."

Other disciplines' "Hierarchy of Needs" address lighting, fenestration, and architectural requirements. When a Smart Building level has been achieved, the requirements and technologies from each discipline work in concert, such that the architect's daylighting scheme provide sufficient general illumination that occupants supplement with the electrical engineer's task lighting. This in turn reduces the mechanical engineer's cooling load, and so forth.

While regulations and executive orders (such as EO 13123) emphasize energy efficiency, other emphases are placed on rapid design delivery and reduced design costs, which can conflict with the energy emphasis. Thus, as described in the section on Traditional Building Design, current practice typically does not reach much above level 1 (basic needs) or at best level 2 (latest technology) in each discipline's hierarchy.

Achieving any higher level requires collaboration among the disciplines. Ideally, this collaboration should occur as early as possible in the design process. The current trend towards conducting "charrettes" fills this need perfectly. A charrette is an intense period of development in which professionals work closely with the client to determine requirements. Planning charrettes are used to develop the functional requirements for a project. Design charrettes are used to rapidly develop conceptual solutions. The basic premise is that by involving the client in key design decisions, there will be fewer changes during the detailed design phase, reducing design time, cost and increasing the quality of the built product. Design charrettes have been used successfully to achieve more optimal goals for the building (Green Building Report, http://www.facilitiesnet.com). However, this technique may increase P&D (Planning and Design) costs, which is at odds with the emphasis on cost minimization.

It is generally accepted that charrettes increase customer satisfaction, but it remains to be seen if the reduction in changes during detailed design will offset the additional effort during preliminary design.

Engineer Technical Letter (ETL) 1110-3-491, "Sustainable Design for Military Facilities," recognizes the worth of design charrettes:

> 4. Project Design Team.
>
> a. Only through an interdisciplinary approach can true sustainability be achieved. Technical Manual 5-803-14, S*ite Planning and Design*, describes the design team. Guidelines set forth in the Architectural Engineering Instruction (AEI) on Installation Support should be followed in establishing the design team. The makeup of the team will be deter-

mined by the particular type of project, but members much achieve a common understanding of environmental and energy conservation concerns. All members of the design team should participate in initial goal setting and should also attend the design charrette.

b. Set clear and specific environmental and energy conservation goals for the project. Quantify goals wherever possible; for example, energy use, water use, allowable levels of volatile organic compounds (VOC) emissions, etc. The Environmental members of the design team shall educate the entire team about opportunities for incorporating sustainable design.

5 Automating Energy Concerns in Building Design

General

Design and analysis tools can help the designer optimize the building's energy consumption and cost, and also to satisfy other considerations. While load calculation and energy analysis tools have been around for decades, these are useful only when the designer is comparing specific technical solutions. A more effective tool would guide the designer in choosing what should be added to the base case building, and would illustrate how that "something" fits into the overall optimization scheme. Since not all design teams have an energy experts as a member, the following tools may help to fill the need by helping to identify appropriate technologies.

Energy-10

Energy-10 is a product of U.S. Department of Energy (DOE), National Renewable Engineering Laboratory (NREL). This tool is marketed by the Sustainable Buildings Industrial Council and benefits from regular upgrades and revisions. Its main strength is that it is easy to use, such that it has become well accepted in the architectural community. There are currently over 1200 registered users throughout the world.

Figure 3 shows how Energy-10 can be used throughout the design process. The designer sets up an initial "base case" and generates a "low-energy case." This can then be used to compare several strategies (selected automatically or by the designer) using full-year simulations. Strategies may be ranked by energy usage, energy cost, etc. This step is used to set the performance goals for the design. During design, actual building configurations can be checked and sensitivity feedback given to the energy designer (note that an "energy expert" is not required). These studies can help define the final strategies. After the design is well set, performance can be compared with the original goals.

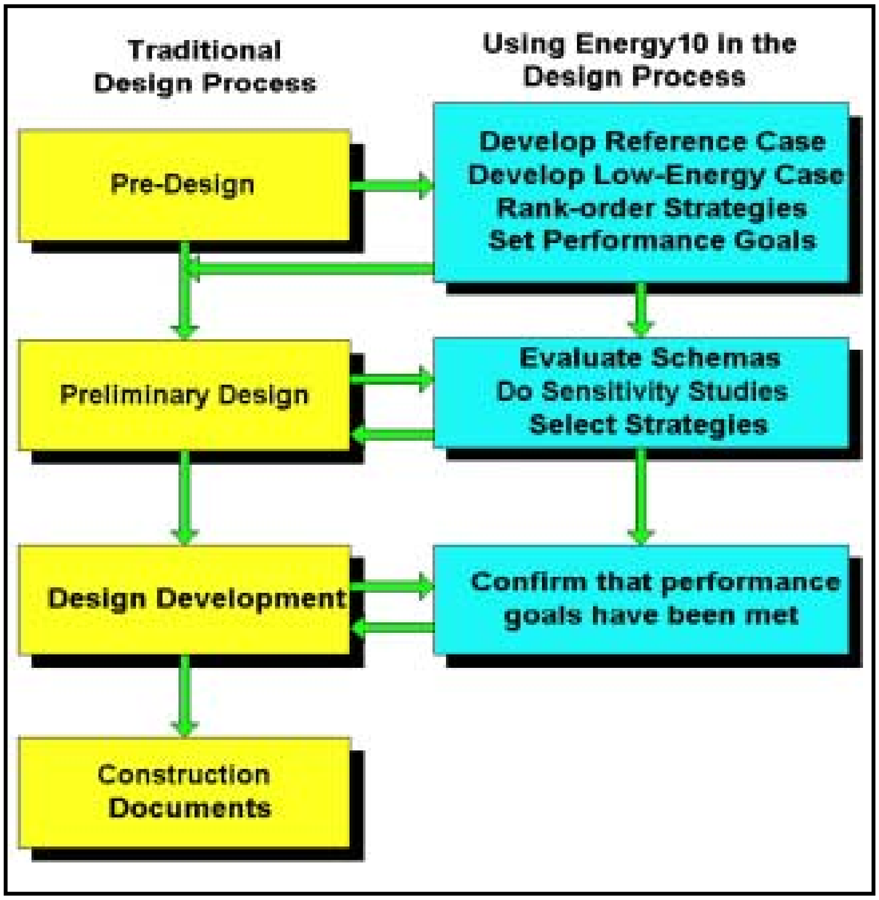

Figure 3. Energy 10 used in design process (source: Clyne 1996).

Drawbacks of the current Energy-10 system are that it: (1) has been designed for smaller buildings (10,000 sq ft), though the principles for larger buildings would be similar, and (2) only two zones are used to define the building (each zone has different thermal loads and uses). This model could work well even for large buildings that have simple layouts and spaces with similar functional requirements. However, these limitations would cause the program to give inaccurate result for large, complex buildings. Figures 4 through 8 give example results from Energy-analyses.

Energy-10 can compare energy costs (Figure 4) as well as energy usage (Figure 5). Note that there is not always a direct correlation between the two, because some strategies (load shifting, peak shaving) can result in increased energy consumption at the same time that energy costs become lower.

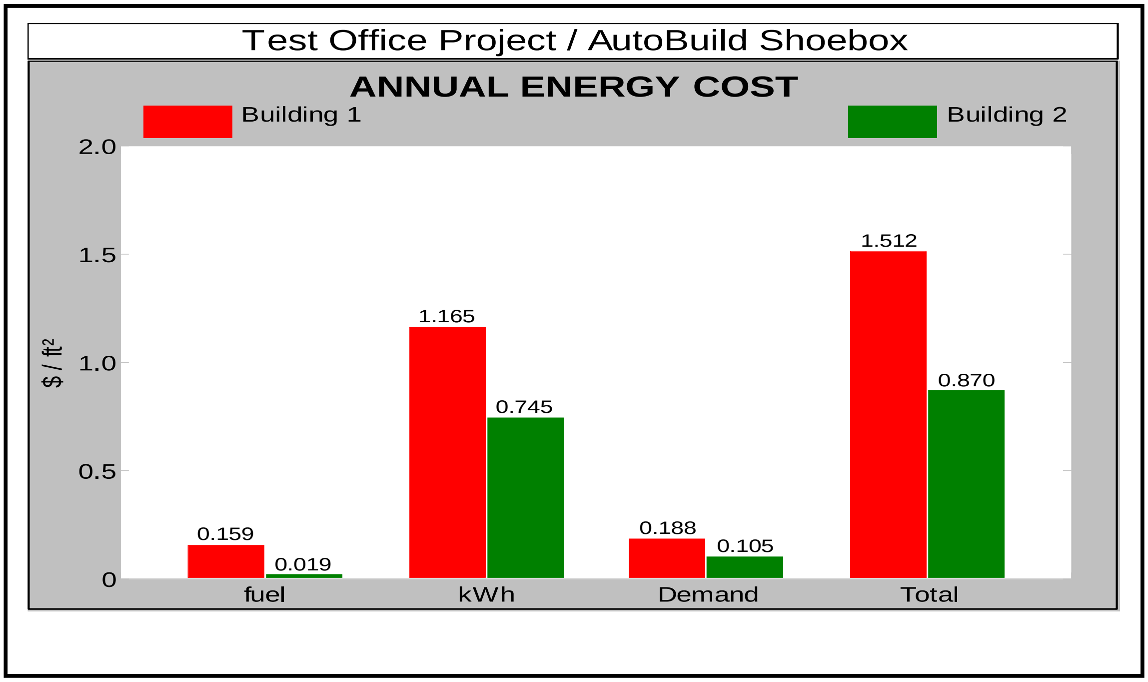

Figure 4. Example Bldg. 1 vs. Bldg. 2 energy costs.

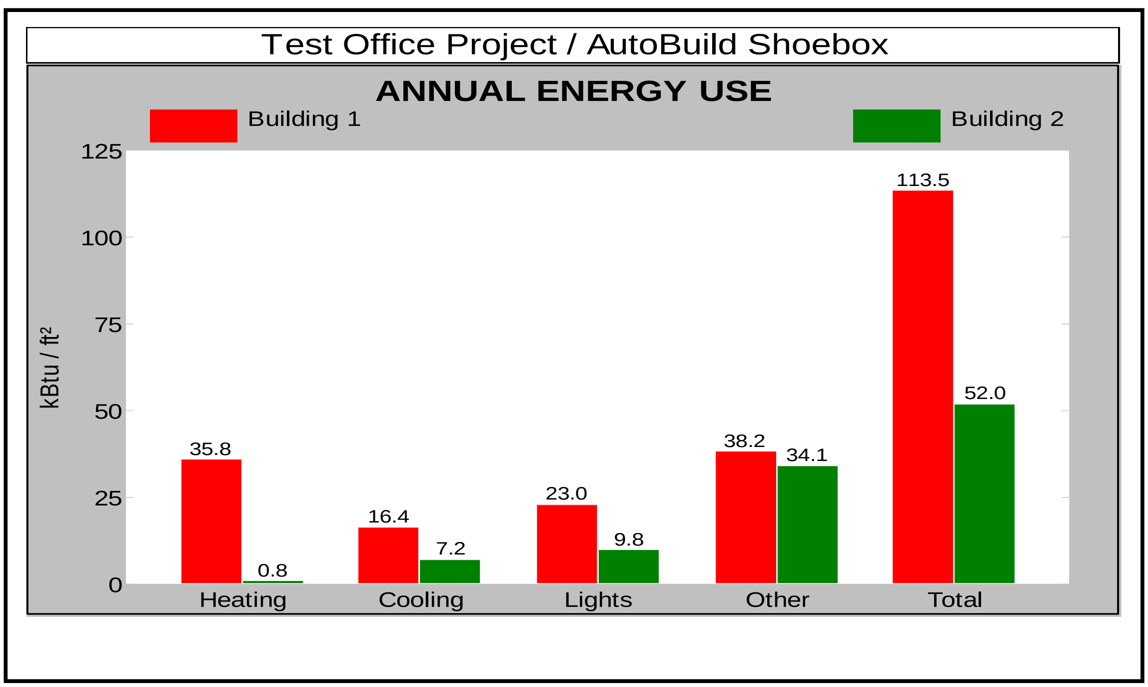

Figure 5. Example Bldg. 1 (designer) vs. Bldg. 2 (automatic) energy use.

Energy-10 can also isolate particular types of (potentially scarce) energy, for example, by comparing kWh consumption (Figure 6).

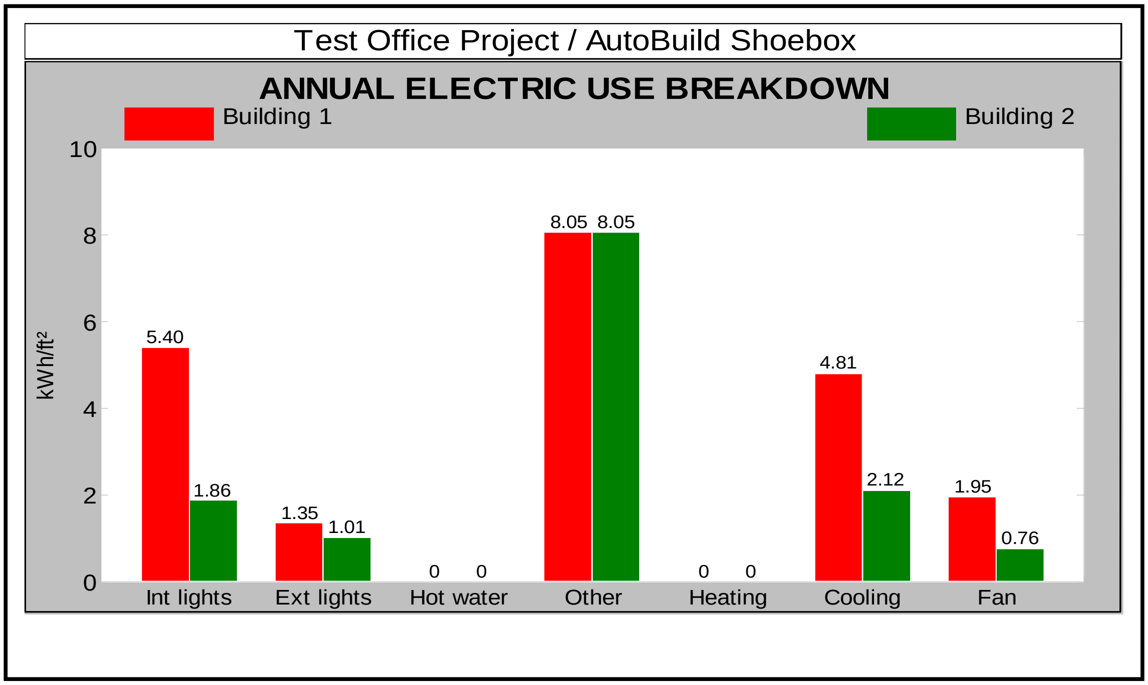

Figure 6. Comparison of kWh usage.

The real power of Energy-10 lies in its ability to rank capabilities. Figures 7 and 8 show an example strategy selection, as well as the method of application. The results easily show the "low hanging fruit."

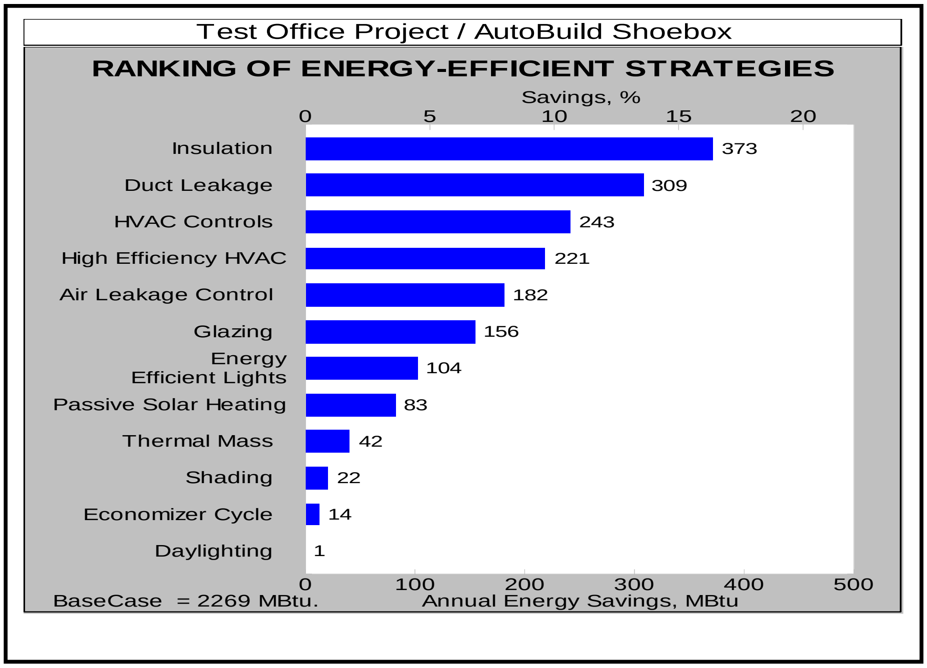

Figure 7. Rank of strategies by energy savings.

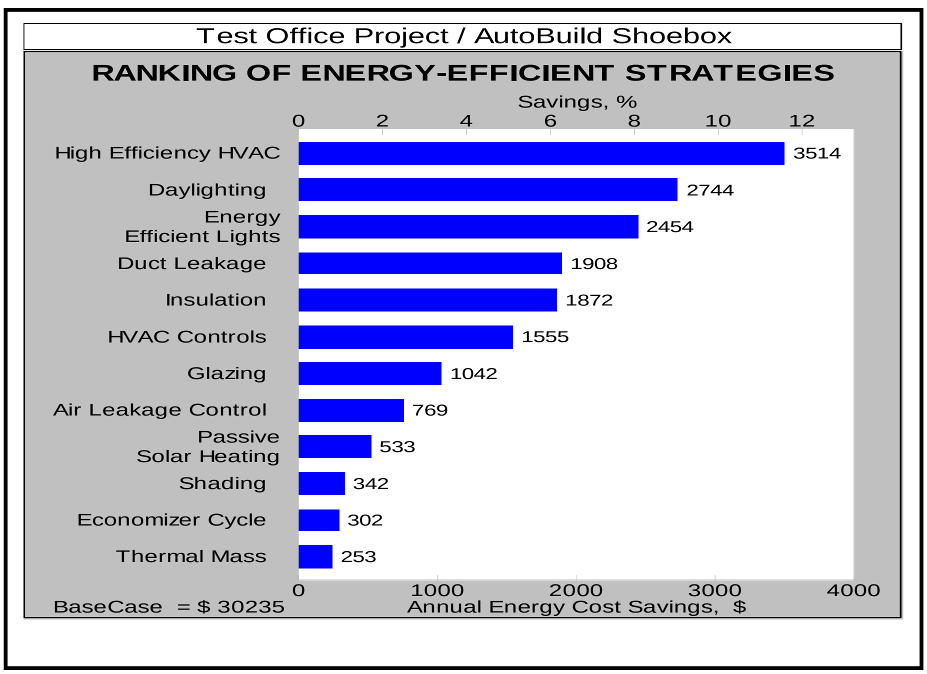

Figure 8. Rank of strategies by cost savings.

As currently configured (two zones, minimal geometric representation), Energy-10 is very useful. However, enhancing the current scheme to address more complex buildings and architectures will result in a cumbersome data entry problem for users. Plans are underway to support complex architecture though a graphical entry interface. Though that will be useful, it may become burdensome as designers will now have to enter these graphics in two systems: first in Energy-10 and then later in the Computer Aided Drafting (CAD) system that will produce the construction documents.

6 Integrating with CAD Systems

A recent study (Vogelsang 1998) surveyed 50 design professionals on their practices in designing chilled water plants. The study typified design practice levels in three categories:

1. Little or no hourly simulation
2. Hourly simulation
3. Hourly simulation with full calibration.

Over half of these did “little or no” hourly simulation during design. If these level 1 respondents did an occasional hourly simulation, their reasons included:

1. When required by owner or Government
2. When it is a large project
3. When time and budget permits.

Interestingly, many of them typically did a complete load analysis, either automated or “back of the envelope.”

The duplication of effort in producing (and maintaining the consistency of) CAD geometry and an energy analysis model has been a key barrier to widespread acceptance of detailed energy analysis tools such as the Building Loads and System Thermodynamics System (BLAST) (Nemeth 1993), and DOE2. Ideally, programs such as these should be able to converse with CAD systems and vice versa. Two emerging technologies show promise for solving this problem; CAD tools are becoming model-based, and international standards are being developed to exchange information between these types of tools.

Model-Based Design

In a recent survey (Lam et al. 1999), it was noted that one of the limitations of current building simulation tools was lack of integration with Computer Aided Design and Drafting (CAD) systems. Historically, the barrier to this integration was that CAD models consist of simple geometric primitives such as lines and arcs while energy analysis applications make use of more specialized models.

Humans excel at feature recognition, and are able to interpret groups of CAD primitives as walls, windows, and zones needed for energy analysis. Automating this capability is a challenging computer science problem due to seemingly minor differences in drawing styles. For example, the lines representing the corner of a room might not quite intersect, or they might be drawn using a color or layer/level reserved for plumbing.

The first mainstream CAD application to support more sophisticated models was Release 14 of Autodesk's AutoCAD ™ (R14). When R14 was released in June of 1997, it included ObjectARX (AutoCAD Runtime Extension) technology, a C++ variant for the development of custom applications. ObjectARX provided the means to create object-oriented models within the CAD environment.

Since that time, the maker of MicroStation, Bentley Systems, Inc. (Bentley) has released ProjectBank, a multi-format repository for engineering models. On the surface, ProjectBank provides change tracking and merge capabilities, allowing multiple users to simultaneously work on the same drawing. Under the hood, ProjectBank is an object-oriented database; "drawings" are generated from the underlying product model by a viewer (translator). This technology allows, for example, a structural engineer working on a load-bearing wall to instantly share changes with the architect working on the floor plan. With the appropriate viewers, ProjectBank could just as easily support the seamless integration of energy analysis applications.

ObjectARX and ProjectBank both address the mechanism for CAD and energy analysis integration, but not the information content. Traditional CAD models lack information about composition (i.e., thermal zones) and physical properties (transmissivity, thermal conductivity, etc.) required for energy simulations. What is needed is a lingua franca for the AEC community—a universal representation that contains sufficient information for each player in the facility design, construction and operation lifecycle. Most major CAD vendors have proposed solutions to address this need. Graphisoft's solution is to use the Graphic Description Language (GDL) from their ArchiCAD product as an open standard. GDL is a solid modeling programming language that predates ObjectARX. ArchiCAD models are composed of a limited number of architectural objects such as walls, slabs, and roofs, but the only way to store "non-CAD" data is through links to relational databases; the mechanism exists, but the content is not developed.

Similarly, Autodesk's solution is an industry-specific extension to ObjectARX that includes architectural objects ranging from ceiling grids to walls, called the "AEC Object Modeling Framework" (OMF). OMF does not contain "non-CAD" data, and there are restrictions against extending OMF, even without the restrictions we are left with a mechanism, but not content. Bentley has yet to deliver their solution, the Engineering Component Model (ECM), so the author reserves judgment on how well it will support energy analysis data requirements.

Interoperability Standards

So where does the content to support integration come from? The most expeditious way to exchange information between a single CAD application and a single energy analysis tool is to develop a custom interface (Figure 9). This interface can be tailored to take advantage of the particular information requirements and exchange mechanisms of the two applications.

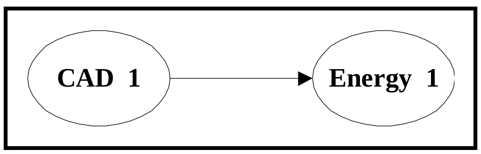

Figure 9. Custom application interface.

The custom interface model works well for firms that dictate the use of a small number of applications. It has less appeal for organizations that allow designers to choose their toolsets. Since no two CAD applications (or energy analysis tools) have quite the same internal model, information requirements and import/export capability, new interfaces must be developed for each application. The total number of interfaces equals the number of CAD applications times the number of analysis tools (Figure 10). The maintenance cost for this approach increases dramatically as one attempts to keep up with new versions, features, and operating systems, all of which evolve at different rates.

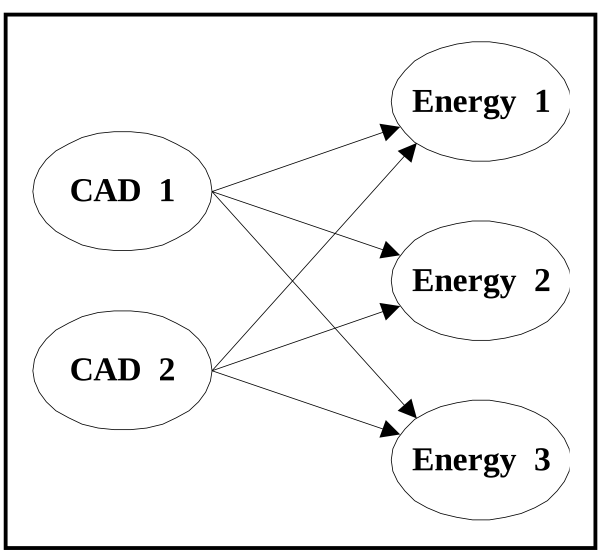

Figure 10. Custom interface—multiple applications

As the number of applications grows, the most cost effective exchange mechanism is to use an intermediate industry standard, either de facto or sanctioned by a body such as ISO (Figure 11). This approach requires a minimal number of interfaces. In addition, if there is sufficient demand, the application vendor may include support for the standard in the product. However, standards are slow to develop and usually cannot take advantage of the latest features of a particular application.

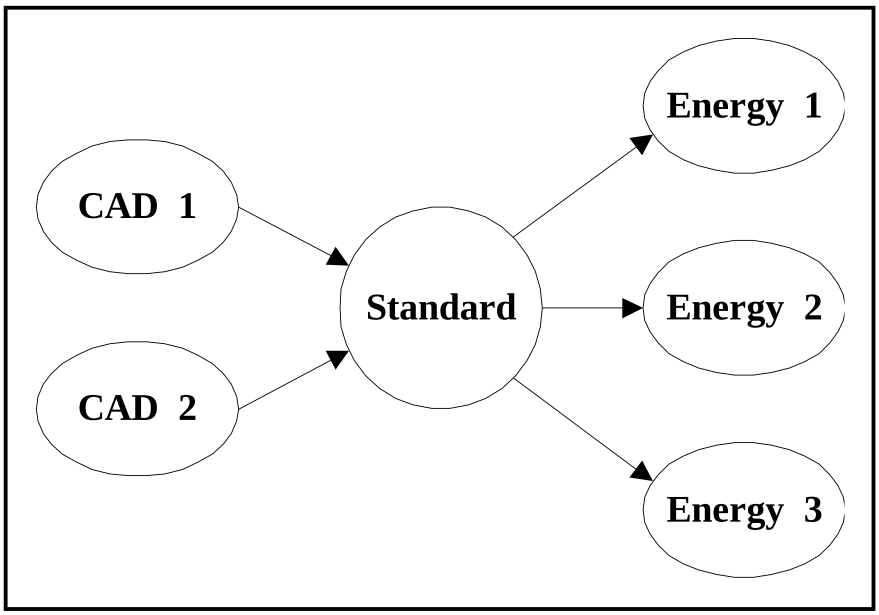

Figure 11. Standards-based interoperability.

The International Alliance for Interoperability (IAI) was formed in 1995 to promote interoperable software across the building's life cycle. They have defined a model-based standard, called the Industry Foundation Classes (IFC), that supports interoperability between CAD systems, design analysis programs, cost estimating software, facility management programs, and other software used in the building construction community. Programs that support IFCs are able to exchange information by reading from, or writing to, the IFC project model in one of several formats including ISO Part 21 files and aecXML file formats.

BLIS (Building Life Cycle Integrated Systems) is a consortium of more than 40 public and private sector software developers dedicated to providing IFC-based software applications. Some of the first organizations (products) to bring such applications to market are:

- Commonwealth Scientific Industrial Research Organization—CISRO (Con-Viewer), Australia
- Graphisoft, Inc. (ArchiCAD), Hungary

- Lawrence Berkeley National Laboratory—LBNL (EnergyPlus), USA
- Microsoft (Visio Professional 2002), USA
- Olof Granlund Oy (RIUSKA), Finland
- Pacific Northwest National Laboratory—PNNL (ComCheck EZ), USA
- Skanska AB (Facets), Sweden
- Solibri (Model Checker), Finland
- Timberline Software Corporation (PECAD), USA
- YIT Constructions (COVE), Finland.

Of particular interest is EnergyPlus. This state-of-the-art energy analysis engine is designed to be integrated into applications created by independent third-party developers. EnergyPlus includes the ability to read building geometry from IFC models, greatly reducing the effort to perform energy analysis simulations.

While this integration will clearly make the simulation tools more accessible to designers, it does have potential drawbacks. First, there may be a tendency to "take the building structure" from the CAD system and "throw it into the simulation tool." While this will provide the most accurate results, it may also require substantially more effort on the part of the user to set up than the simple two-zone model used by Energy-10. Second, modeling every nook and cranny of a building will make the simulation tool work harder. If a designer wants to perform several alternative studies (such as those that Energy-10 does automatically), the time required to complete the simulation could become excessive.

One of the strengths of the IFC model is that it explicitly models spaces. Most CAD systems are geometry-centered; they have little need for abstract concepts like space. By contrast, spaces are a critical part of most energy analysis models, as they serve as a place to reference set points and other comfort parameters, occupancy, internal loads etc. The IFC model supports both perspectives, reducing the likelihood that the entire building structure will be thrown into the simulation tool.

Building Composer is an IFC-enabled suite of applications. Architectural programs and associated criteria from Criteria Composer are exchanged with Layout Composer, which comes in AutoCAD or MicroStation versions (Figure 12). Work is currently underway to extend this interoperability to include BLIS applications as well as the Parametric Cost Estimating System (PACES) from Talisman Partners.

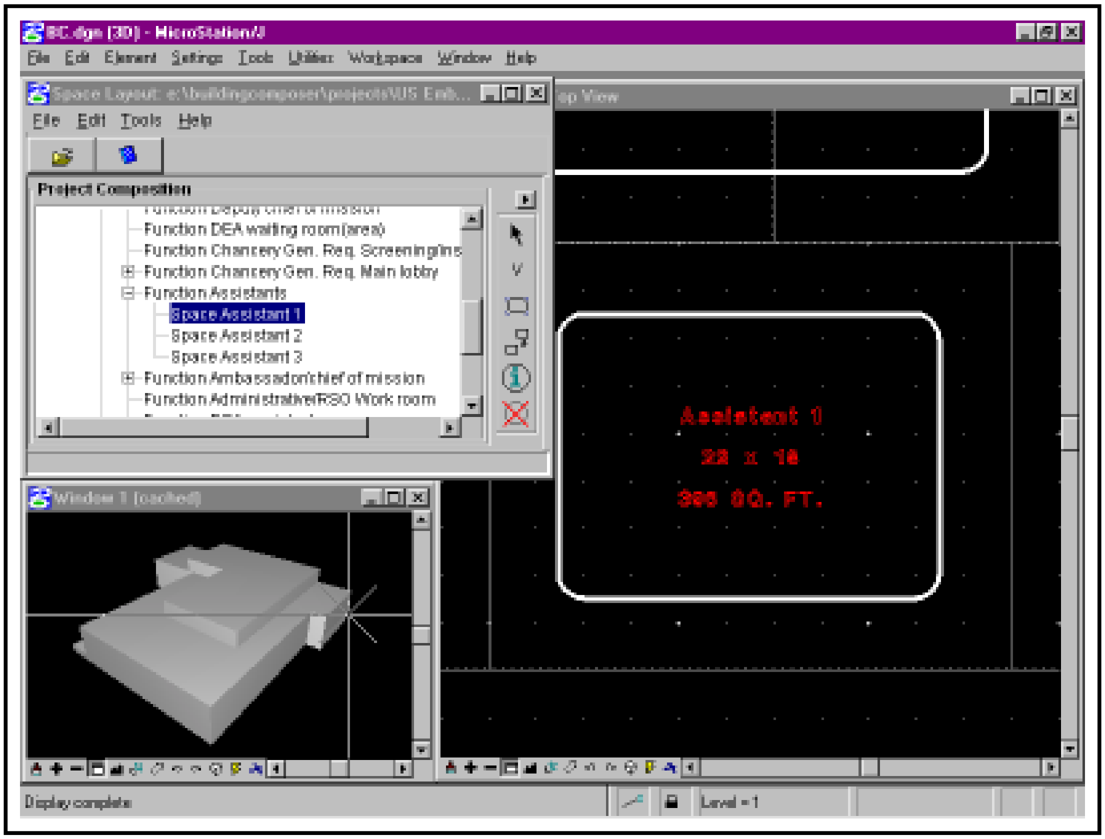

Figure 12. Layout Composer—IFC-enabled CAD integration.

These three capabilities can be combined to provide a streamlined energy analysis capability. Building Composer could associate energy-related criteria with IFC spaces. A CAD tool could be used to model the building's geometry, and EnergyPlus could automatically read this information and set up an energy simulation with almost no burden on the user.

Building Design Advisor

Another tool that supports the IFC class structure is the Building Design Advisor from Lawrence Berkeley National Laboratory. Papamichael et al. (1999) describes the Building Design Advisor (BDA) as a software environment aimed at facilitating the integrated use of multiple simulation tools and databases to support informed decisions from the early stages of building design through the final specification stages. As discussed in this paper, BDA is designed to automate Performance Prediction and Performance Evaluation (Figure 13).

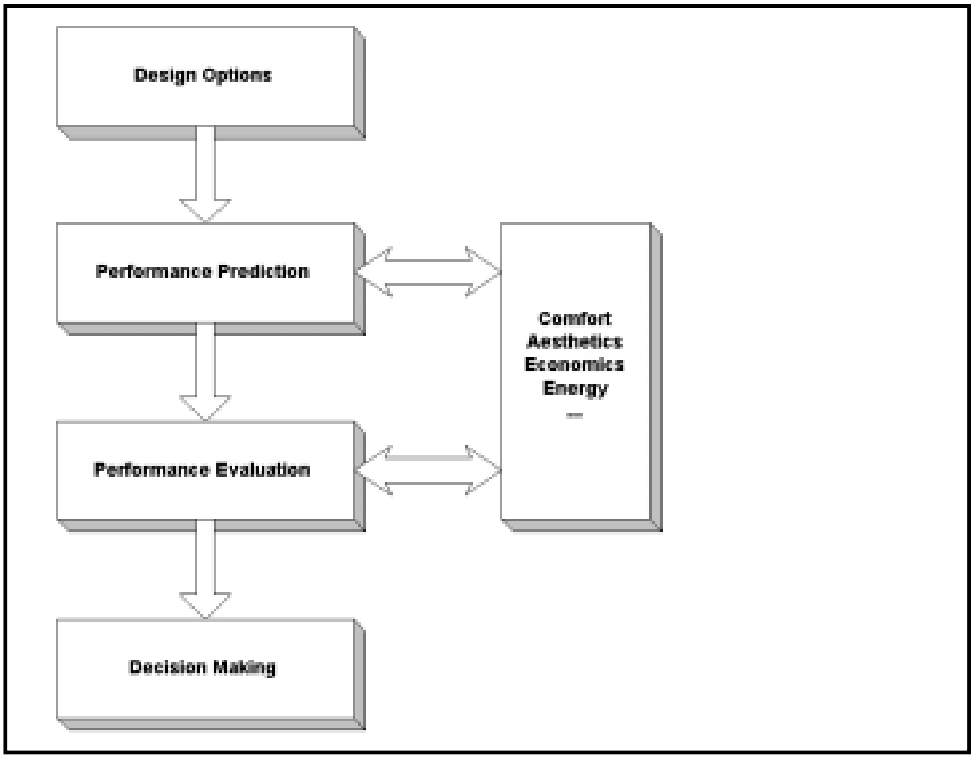

Figure 13. Building design decisions.

As Figure 13 shows, Building Design Decisions require performance prediction and evaluation with respect to multiple metrics. Since different performance evaluations will be done with differing software, communicating the building model to each of these can be simplified if all the software programs conform to some standard input and output procedures (such as IAI IFC).

BDA supports exploration of a wide variety of alternatives, but it requires much more user interaction than Energy-10. Whereas Energy-10 has prescribed a set of tests to be done on a building, BDA will let the user determine the course for evaluations. In BDA, each alternative is called a "solution" (Figure 14). New solutions may be based on a previous solution, greatly reducing data entry requirements (and the associated chance of human error).

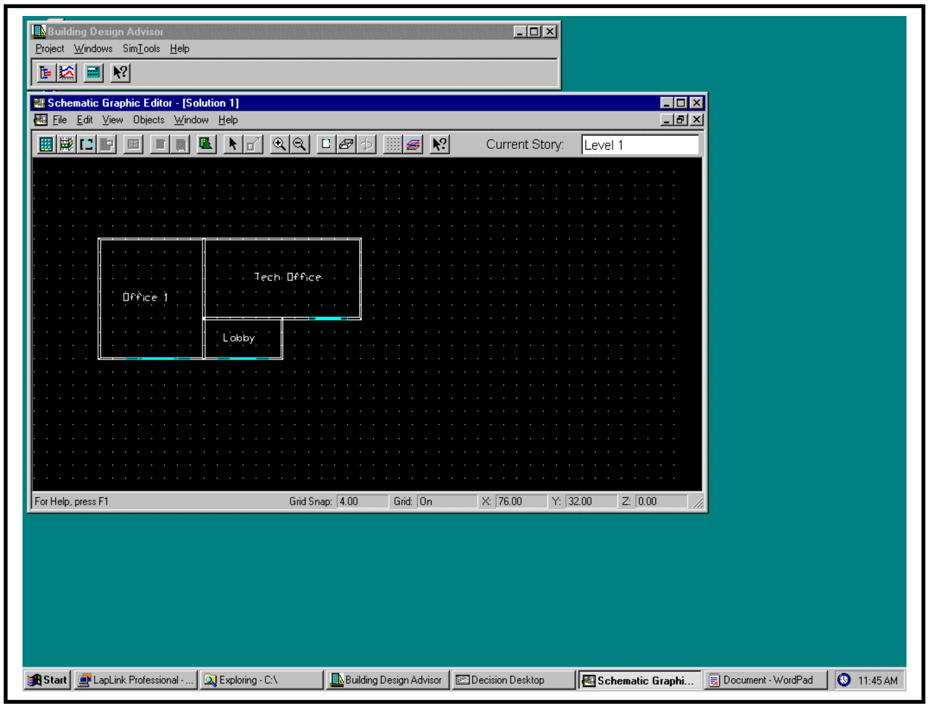

Figure 14. BDA solution screen.

BDA includes a powerful Building Browser (Figure 15) in which the user selects each metric of the building performance to be displayed.

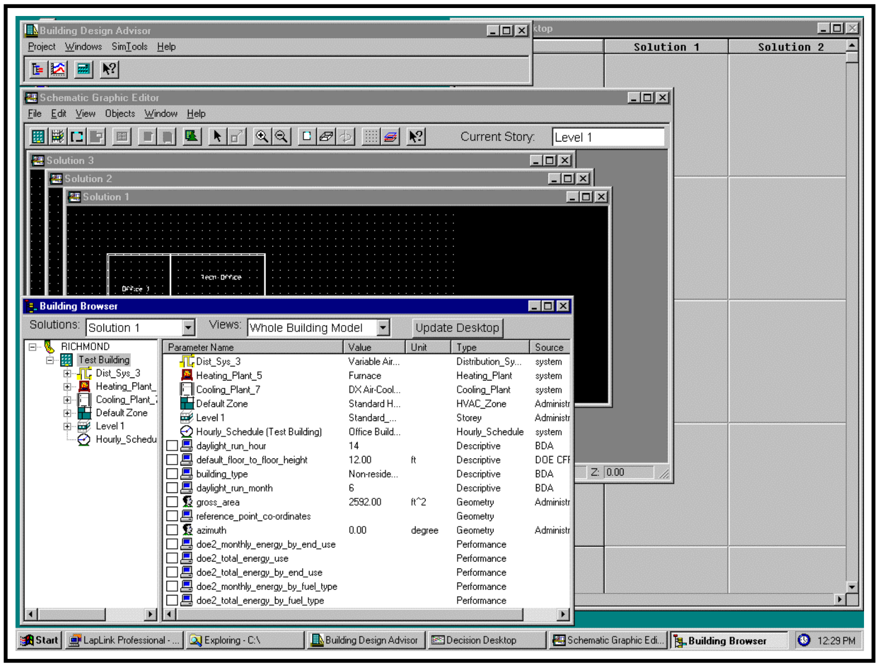

Figure 15. BDA building browser screen.

Once metrics are selected, the "Decision Desktop" (Figure 16) is used to compare the performance of each solution.

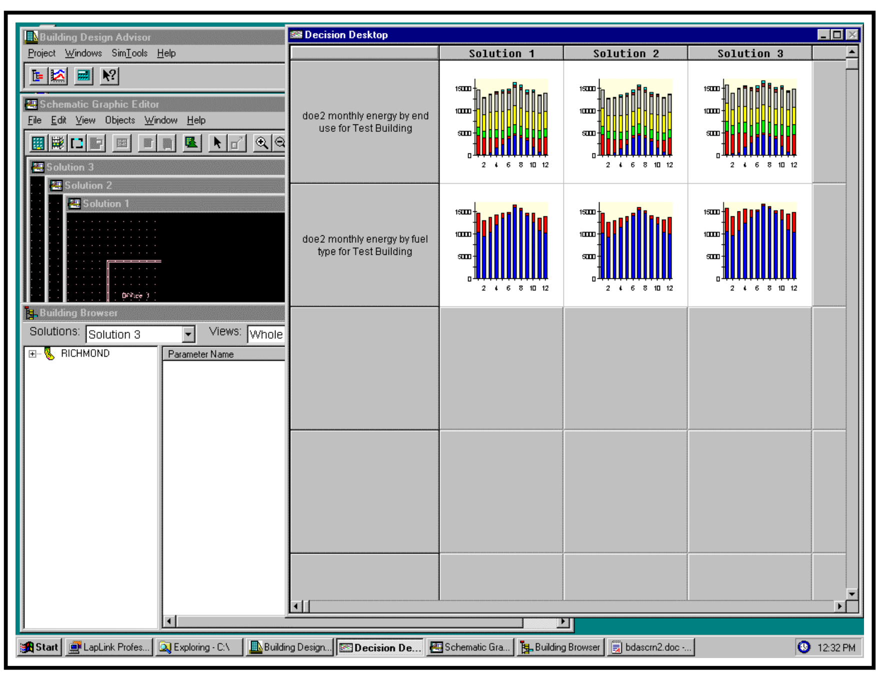

Figure 16. BDA decision desktop.

The performance of a particular solution can be displayed with legends, etc. (Figure 17).

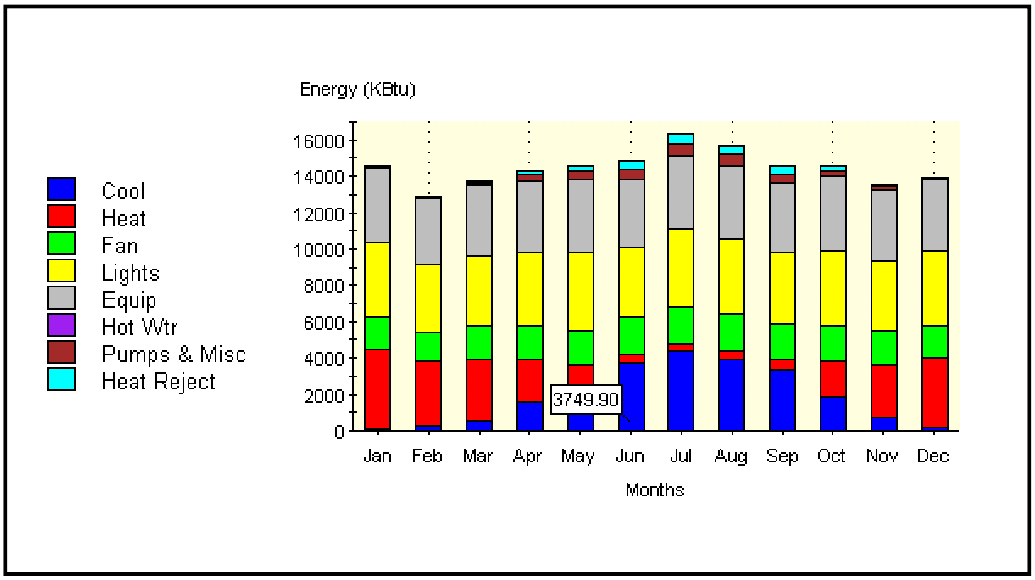

Figure 17. BDA solution performance, with legend.

7 Conclusions

This study has used two readily available, Government-sponsored energy analysis tools to illustrate how designers could identify energy-efficient concepts for inclusion in their building designs. Both of these tools use the tactic of comparing alternative building configurations to assist the designer in determining which energy saving features to incorporate. These tools are unique in the marketplace—there are no (known) similarly configured commercially available software applications that do this function. Most commercially available tools may let the user choose different configurations, but they will not typically record the alternative path was used to achieve the final result (i.e., compare the differences in the buildings considered).

This study concludes that automation can help the building designer(s) achieve more energy-efficient buildings. However, it is not necessarily an easy task. Building configurations are quite complex; the interactions of various energy-consuming pieces of the building are not obvious without extensive analysis. Designers find it difficult to keep up with all the new, potential technologies—let alone then analyzing each building for optimal energy usage.

This study has identified two key technologies to help overcome these barriers. First, integrating energy analysis tools with CAD applications can reduce the effort required to perform energy analysis. This integration is being supported by two trends, model-based CAD applications and standards like IAI's Industry Foundation Classes, which support interoperability between AEC tools. Second, criteria-based design tools such as *Building Composer* provide a conduit for organizations to deploy energy-efficient strategies. This technology enables criteria such as target energy budgets, preferred lighting, HVAC, and exterior enclosure systems to be automatically incorporated into building design, improving energy efficiency and saving the designer precious time.

A powerful capability emerges from using interoperability standards to unite criteria-based design, model-based CAD and software that helps identify energy-efficient alternatives. The intelligent defaults (criteria) and building model (geometry) provide the detailed information required for energy analysis at an early design stage, rather than after major decisions have already been made. The identification of energy-saving alternatives at this crucial early design stage allows the architect to easily incorporate energy saving design features.

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Appendix A: Current Federal Regulations

Facility managers are required to follow a wide variety of Federal laws, Executive Orders, and Executive Memoranda to reduce the energy and environmental impacts of the buildings they manage. These laws and regulations already direct facility managers to be proactive in their efforts to reduce resource consumption, reuse and recycle materials, and dramatically reduce the impacts of Federal government activities on the environment. Although they are required to comply with the many specific directives in these documents, many facility managers may be unaware of the actions they can take with regard to implementation. This Appendix lists the major Federal regulations governing energy and environmental actions, together with their important provisions, in chronological order. Most of the information included in this Appendix was taken from "Greening Federal Facilities," *Federal Energy Management Program*, augmented with the latest executive orders.

Federal Laws

Energy Policy and Conservation Act (EPCA) of 1975

EPCA was the first major piece of legislation to address Federal energy management. This law directed the President to develop a comprehensive energy management plan. EPCA has largely been overtaken by later legislation.

Resource Conservation and Recovery Act (RCRA) of 1976

RCRA §6002 established a Federal mandate to "Buy Recycled." RCRA §1008 and §6004 require all Federal agencies generating solid waste to take action to recover it.

National Energy Conservation Policy Act (NECPA) of 1978

NECPA specified the use of a life-cycle costing methodology as the basis for energy procurement policy and specified the rate for retrofit of Federal buildings with cost-effective energy measures. Title V of NECPA was codified as the Federal Energy Initiative.

Comprehensive Omnibus Budget Reconciliation Act (COBRA) of 1985

COBRA, a 1-year funding bill, provided Federal agencies with an alternative source of funding for energy-efficiency investments. For the first time, agencies were encouraged to seek private financing and implementation of energy-efficiency projects through "shared energy savings" (SES) contracts.

Federal Energy Management Improvement Act (FEMIA) of 1988

The Federal Energy Management Improvement Act mandated a 10 percent reduction in per-square-foot energy use by Federal buildings between 1985 and 1995, marking the first time that Congress specified the level of savings that had to be achieved.

Energy Policy Act of 1992 (EPACT)

Th Energy Policy Act of 1992 increases conservation and energy-efficiency requirements for government, energy, and consumers; for Federal agencies, requires a 20 percent reduction in per-square-foot energy consumption by 2000 compared to a 1985 baseline; provides authorization for DOE to issue rules and guidance on Energy Savings Performance Contracts (ESPCs) for Federal agencies; requires Federal agencies to train and utilize energy managers; directs the Office of Management and Budget to issue guidelines for accurate assessment of energy consumption by Federal buildings; and directs GSA to report annually on estimated energy costs for leased space.

10CFR435

10CFR435 establishes performance standards to be used in the design of new Federal commercial and multifamily high rise buildings. Some of the guidelines are relevant to retrofits.

10CFR436

10CFR436 establishes procedures for determining the life-cycle cost effectiveness of energy conservation measures, and for prioritizing energy conservation measures in retrofits of existing Federal buildings.

Executive Orders

Executive Order 12759, "Federal Energy Management" (17 April 1991)

EO 12759 extended the FEMIA energy reduction requirements for Federal buildings to 2000, requiring a 20 percent reduction in per-square-foot energy usage from 1985 levels. This executive order was replaced by Executive Order 12902 (p 35).

Executive Order 12843, "Procurement Requirements and Policies for Federal Agencies for Ozone-Depleting Substances" (21 April 1993)

EO 12843 requires Federal agencies to maximize the use of safe alternatives to ozone-depleting substances by:

1. Revising procurement practices
2. Modifying specifications and contracts that require the use of ozone-depleting substances
3. Substituting non-ozone-depleting substances to the extent economically practicable
4. Disseminating information on successful efforts to phase out ozone-depleting substances.

Executive Order 12844, "Federal Use of Alternative Fueled Vehicles" (21 April 1993)

This requires the Federal government to adopt aggressive plans to acquire, subject to availability of funds and considering life-cycle costs, alternative fueled vehicles, in numbers that exceed by 50 percent the requirements for 1993 through 1995, set forth in the Energy Policy Act of 1992.

Executive Order 12845, "Requiring Agencies to Purchase Energy-Efficient Computer Equipment" (21 April 1993)

EO 12845 requires all acquisitions of microcomputers, monitors, and printers to meet U.S. Environmental Protection Agency (EPA) Energy Star requirements for energy efficiency, including low power standby features as defined by EPA Energy Star Standards. Agencies must make Federal users aware of the economic and environmental benefits of energy saving equipment through information and training classes.

Executive Order 12856, "Federal Compliance with Right-to-Know Laws and Pollution Prevention Requirements" (4 August 1993)

EO 12856 explains how Federal agencies are to comply with Emergency Planning and Community Right-to-Know (EPCRA) reporting requirements and offers "leadership options" for Federal agencies in meeting the goals of the Order.

Executive Order 12873, "Federal Acquisition, Recycling, and Waste Prevention" (20 October 1993)

This Executive Order addresses the government's purchasing power, incorporates environmental considerations into decisionmaking, and encourages waste prevention and recycling in daily operations. Federal agencies: (1) must set goals for waste reduction; (2) must increase the procurement of recycled and other environmentally preferable products; and, (3) can retain some of the proceeds from the sale of materials from recycling or waste-prevention programs.

Executive Order 12902, "Energy Efficiency and Water Conservation at Federal Facilities" (8 March 1994)

For Federal agencies EO 12902 requires: (1) a 30 percent reduction in per gross square foot energy consumption by 2005 compared to 1985 to the extent that these measures are cost effective; (2) a 20 percent energy efficiency increase in industrial facilities by 2005 compared to 1990 to the extent that these measures are cost effective; (3) the implementation of all cost-effective water conservation projects; and, (4) the procurement of products in the top 25 percent of their class in energy efficiency where cost-effective and where they meet the agency's performance requirements. In addition to available appropriations, agencies shall use innovative financing and contracting mechanisms including, but not limited to, utility DSM and ESPCs to meet the goals and requirements of EPACT and this order.

Executive Memorandum on "Environmentally and Economically Beneficial Practices on Federal Landscaped Grounds" (26 April 1994)

This requires Federal grounds and Federally funded projects, where cost-effective and practicable, to use regionally native plants for landscaping. It also requires facility managers to promote construction practices that minimize adverse effects on the natural habitat; minimize use of fertilizers and pesticides; use integrated pest management techniques; and, recycle green waste. Water-efficient practices, such as minimizing runoff, using mulches, irrigating using efficient systems, and performing water audits, are also required. Agencies must also establish areas that demonstrate these principles.

Executive Order 13101 on "Greening the Government Through Waste Prevention, Recycling, and Federal Acquisition (14 September 1998)

This appears to be a rewrite (or superceding version) of EO 12783.

Executive Order 13123 on "Greening the Government Through Efficient Energy Management" (3 June 1999)

This new Order builds on and incorporates many of the provisions from EO 12902 expanding its scope and strengthening its management and implementation mechanisms. With respect to efficiency, it establishes a goal to reduce energy consumption per gross square foot by 30 percent in 2005 and 35 percent in 2010, compared to 1985. Achieving this goal will cut annual greenhouse gas emissions by 2.4 million tons from current levels—the equivalent of removing 1.7 million cars from the road and save taxpayers more than $750 million per year. The Order enlarges the pool of candidate sites for energy-efficient projects by including classes of facilities that were previously exempt. Moreover, it directs agencies to look for water savings opportunities and energy savings associated with water use at these sites (EO 13123, "FEMP Focus," Special Issue, 1999).

Executive Order (unknown number) on "Developing and Promoting Biobased Products and BioEnergy (12 August 1999)

This EO establishes an Interagency Council on Biobased Products and Bio-Energy as well as charging the council with preparing an annual strategic plan for biobased products use. This could spin off several technologies to be used in buildings.

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Federal Energy Management Program, DOE/GO-102001-1165, *Greening Federal Facilities*, 2d ed. (May 2001).

Contacts

For more information on Federal rules and regulations relative to energy and environmental actions, contact FEMP's Help Desk at (800) DOE-EREC.

Appendix B: Identified Barriers

During the February 1998 meeting with the designers, a quick 15-minute session identified 59 barriers that the designers could feature as barriers to implementation of any "best available" idea in energy-efficient buildings. Most of the barriers are systemic in the DOD. Overcoming these barriers is not as simple as "mandating" energy efficiency.

Value Engineering Program

Value Engineering is a common scapegoat throughout the three services. In concept, the value engineering program is good; it helps maintain the checks and balances for a construction project. However, it is commonly viewed as a hindrance for new technologies, particularly energy projects where the savings comes from the life cycle of the facility rather than first costs.

For example, in "Mandating Life-Cycle Cost Considerations in Projects," NAVFAC Improvement Plan Tasking 1-2-F, 15 April 1997, stated that "In Theory, Value Engineering is Not One of the Barriers to Implementing Life-Cycle Cost Concepts—But it is Persistently Perceived to Be a Barrier and Often is, in Reality. There is generally no disagreement that value engineering has traditionally been perceived to be a program to reduce first costs and inconsistent with life-cycle cost concepts. Program emphasis in recent years, however, has included life-cycle cost considerations."

Several Value Engineering Studies are available on the CCB. Reviewing them revealed that life cycle cost studies were being performed, but that they were not using the provisions of 10CFR436 to perform the life cycle cost studies for energy related projects.

For example, a VE Study of an Enlisted Personnel Barracks study proposes replacing a gas-fired water heater with instantaneous electric water heaters, notes that a disadvantage of the electric is a "higher cost energy to heat the water" but the life cycle analysis does not take anything into account other than first costs. On the other hand, the same study suggests using LowE Glass rather than the design double pane tinted windows even though higher first costs would result.

(LowE was 16 percent higher cost than the regular double pane tinted windows. The study also notes that energy calculations should be performed for this option).

Source/Reference: Barrier—from common designer folklore. Details from Value Engineering Studies on CCB.

Complexity of New Technology

New technologies may confuse the maintenance/installation personnel even though these technologies may be more energy-efficient and require less maintenance.

Various new technologies have been tried before their time (e.g., occupancy sensors) and have been found wanting. Having this "bad rap" makes installations less likely to try them again—due to occupant complaints.

Emphasis Inhibits Collaboration

Design charrette teams have been shown to tremendously impact the final nature of designs. However, these teams typically cost more P&D (Planning and Design) dollars—a subject that is not popular in DOD design organizations.

Lack of Incentive for Saving Energy

Fuel costs are still low. Emphasis is still on decreased first costs rather than minimizing life cycle costs. Energy savings strategies were taken many times without regard to occupant comfort in the late 1970s—no one wants that to happen again.

Increased First Costs

Energy-efficient opportunities may increase first costs, but decrease life cycle costs. Emphasis is still on keeping first costs minimized, within the programmed amount (PA).

Increased Maintenance Costs

Some opportunities may appear to increase maintenance costs or require more maintenance. These, fortunately, are fewer but still may have this reputation. In the high efficiency boiler example, we can see that decreased maintenance will result as will using CFLs.

Saving Energy vs. Saving Money

Some energy opportunities will save a lot of money but not save energy (e.g., Peak Shaving or Ice Storage systems).

Appendix C: Internet Resources

Given the speed at which the Internet is evolving, any list of resources is out of date as soon as it is compiled. The following is provided both for the use of the near-term reader as well as provide a snapshot of the current state for the readers in the future.

Web Sites

U.S. Department of Energy (USDOE)

Home Page

http://www.energy.gov/

Greening Federal Facilities

http://www.eren.doe.gov/femp/greenfed/3.0/3_1_energy_conservation.htm.

Energy Tools

http://www.eren.doe.gov/buildings/tools_directory/

http://www.eren.doe.gov/buildings/energy_tools/energyplus/

EnergyPlus was released for general use in April 2001. It is a free download that includes a simple editor, documentation, executable program file, weather processor, sample files, and library data sets. Private/third party interfaces will become available in the near future making use of the EnergyPlus technology and adding user-friendliness/domain specificity.

Center for the Analysis and Dissemination of Demonstrated Energy Technologies (CADDET)

http://194.178.172.86/cadinfo.htm.

While the information at CADET is too voluminous to be included here in its entirety, it has lots of practical information.

Energy Efficiency & Renewable Energy Network (EREN)

http://www.eren.doe.gov/

(The Greening Federal Facilities web site is "under" this web site).

Sustainable Buildings Industry Council

http://www.sbicouncil.org/

Energy & Environmental Building Association

http://www.eeba.org/

Energy Ideas Clearing House BBS

http://www.energyideas.org/

California Energy Commission

http://www.energy.ca.gov/

Buildersnet

http://www.buildersnet.org/

Sustainable Design

http://www.cecer.army.mil/SustDesign/index.cfm

Whole Building Design Guide

http://www.wbdg.org/

At least one district has posted a "lessons learned" web site. This information can also be shared with other districts.

Newsgroups

Recently, USACE designers have started UseNet Newsgroups (e.g., usace.mechanical, usace.architectural, usace.cad and others). This may prove a useful resource to share information among the district designers and others.

Email Lists

Electronic mail lists can be joined that discuss topics such as building simulation and many other aspects that address energy use in buildings.

Web-Based Tools

Other information can be found on the web. For example, a generic cost estimate for a building (very useful for Life Cycle Cost studies that are required by 10CFR436) can be found at:

http://www.buildingteam.com

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14. ABSTRACT

Since the mid-1970s, the Department of Defense (DOD) has pursued a strategy of increasing the energy efficiency of its buildings, both in new designs and existing facilities. Designers have effectively produced more energy-efficient buildings, but are also under constant pressure to reduce facility delivery times, first cost, and maintenance requirements. They must also address design considerations such as aesthetics, indoor air quality, and occupant comfort—all factors that can be at odds with minimum energy consumption. Modern information technology offers efficient ways to consolidate, organize, and share the content of laws, regulations, and guidance and implementation documents that relate to building design. Computer programs can help building designers incorporate energy-efficient design measures into new and existing buildings, and help coordinate energy-related considerations with other competing design factors. This study reviewed current practices and technologies that may help building designers better incorporate energy efficiency into all design phases.

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